Fault Recovery in Linear Systems via Intrinsic Evolution

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Fault tolerant systems are design to provide service in the presence of failures.

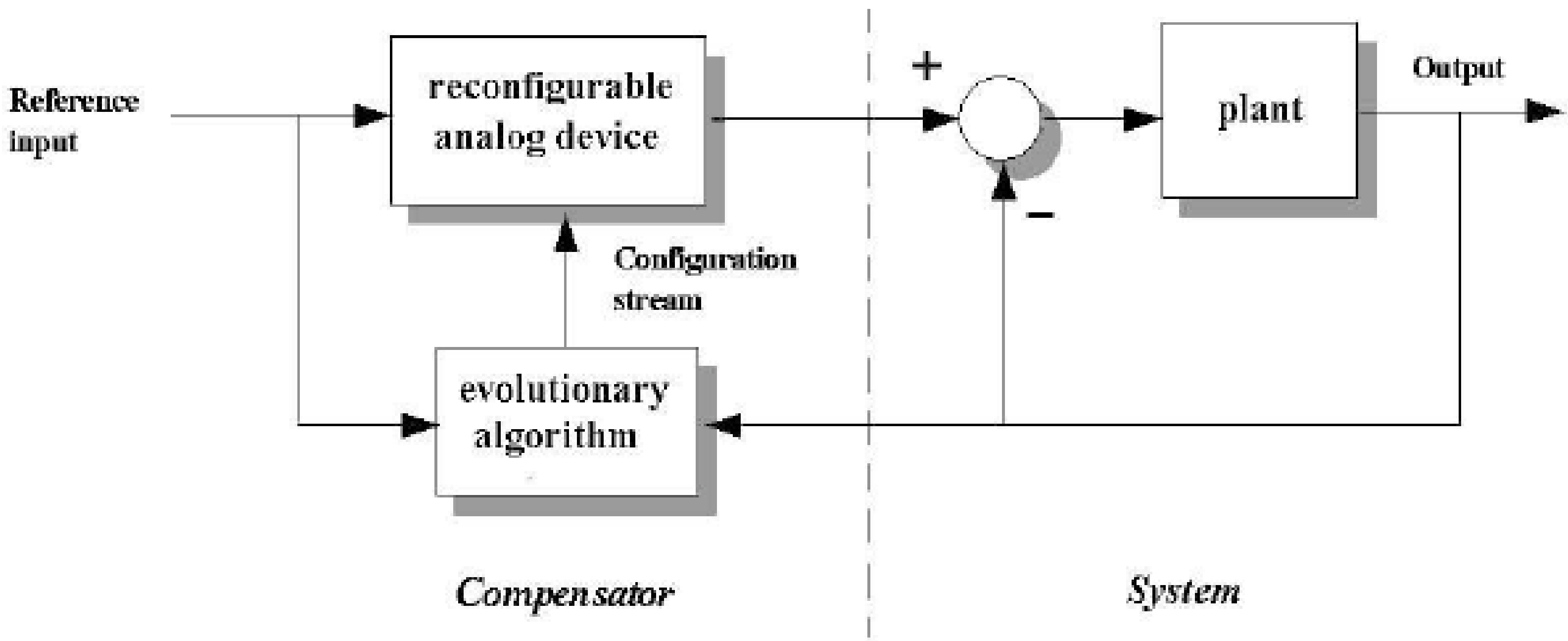
A common way of restoring service when failures occur is by providing redundant hardware that can replace faulty hardware.

But that isn’t always possible. (Consider deep-space probes which have limited space for redundant hardware.)

Reconfiguration may be the only viable fault recovery method when one if forced to contend to severe space and/or weight restrictions.

Much of the previous work on fault recovery using reconfiguration has concentrated on the circuit level.

We focus on the system level. In particular, we consider linear analog systems where access to any internal circuitry— whether faulty or not— is not possible.


Reference
input
reconfigurable
analog device
+
–
plant
Output
Configuration
stream
evolutionary
algorithm
Compensator
System

The system faults we consider are manifested as a sudden change in the plant's bandwidth. This type of fault model represents a broad class of problems fault tolerant systems must content with: *aging effects* and *changing operational environments*.

Consider a simple RC lowpass filter

$$G(s)=\frac{1/RC}{s+1/RC}$$

Capacitor values change over time and also change value when exposed to extreme hot or extreme cold temperatures.   Changes in the capacitor value changes the pole location.

Notes:

1. A decrease in BW makes the plant sluggish

2. An increase in BW makes the plant more susceptible to high frequency noise

3. A 3rd-order plant is sufficient to approximate the behavior of most real systems.

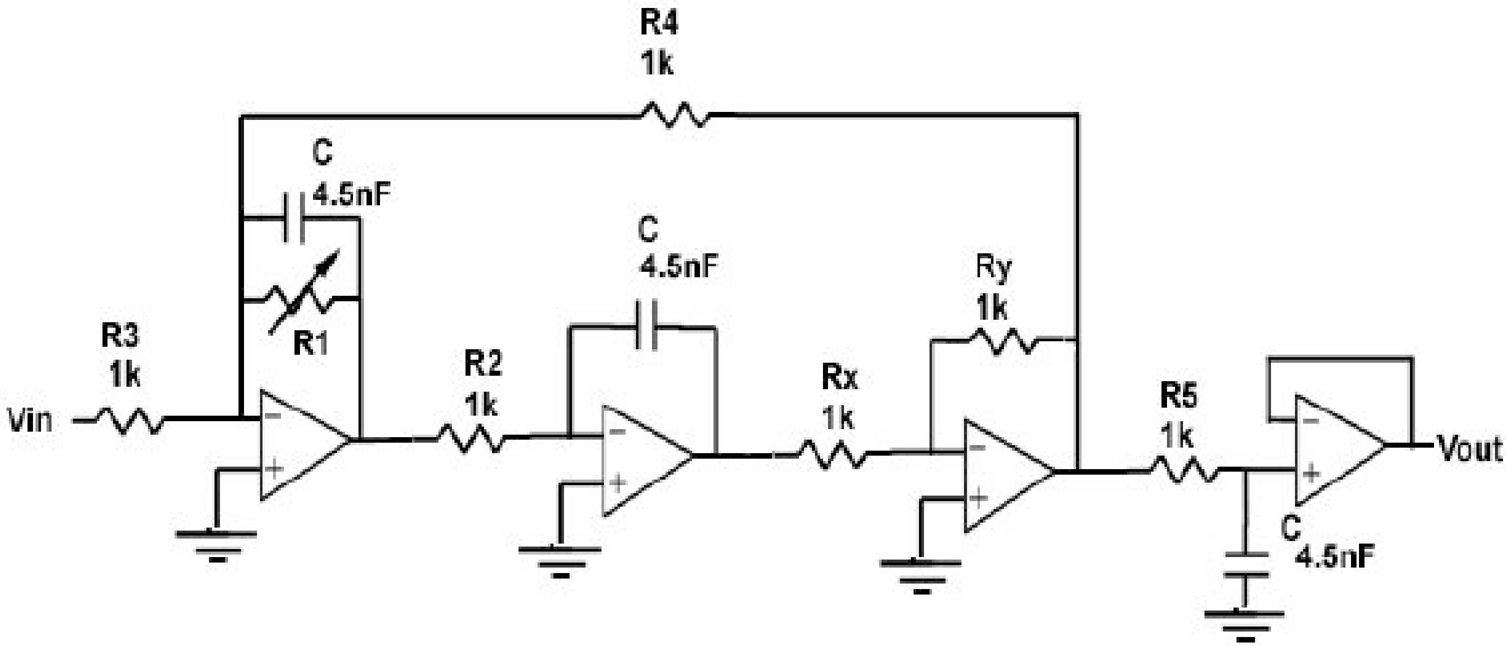
$$G_p(s) = \frac{K_p}{\prod_{i=1}^{3}(s+p_i)}$$

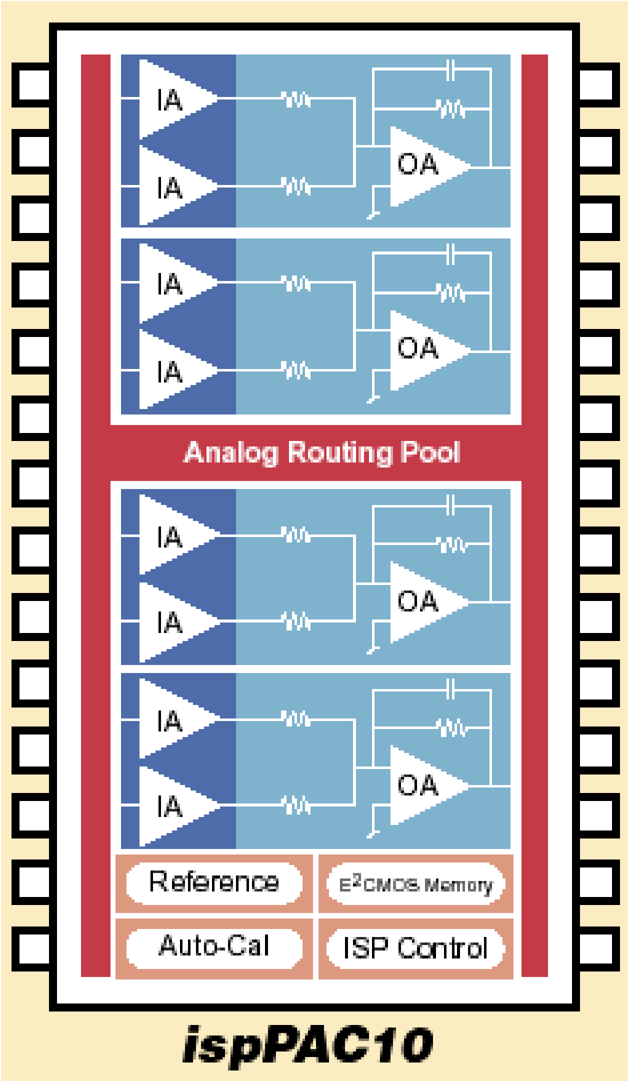
4. A lead compensator increases BW; a lag compensator decreases BW.

5. The transfer function of a compensator is

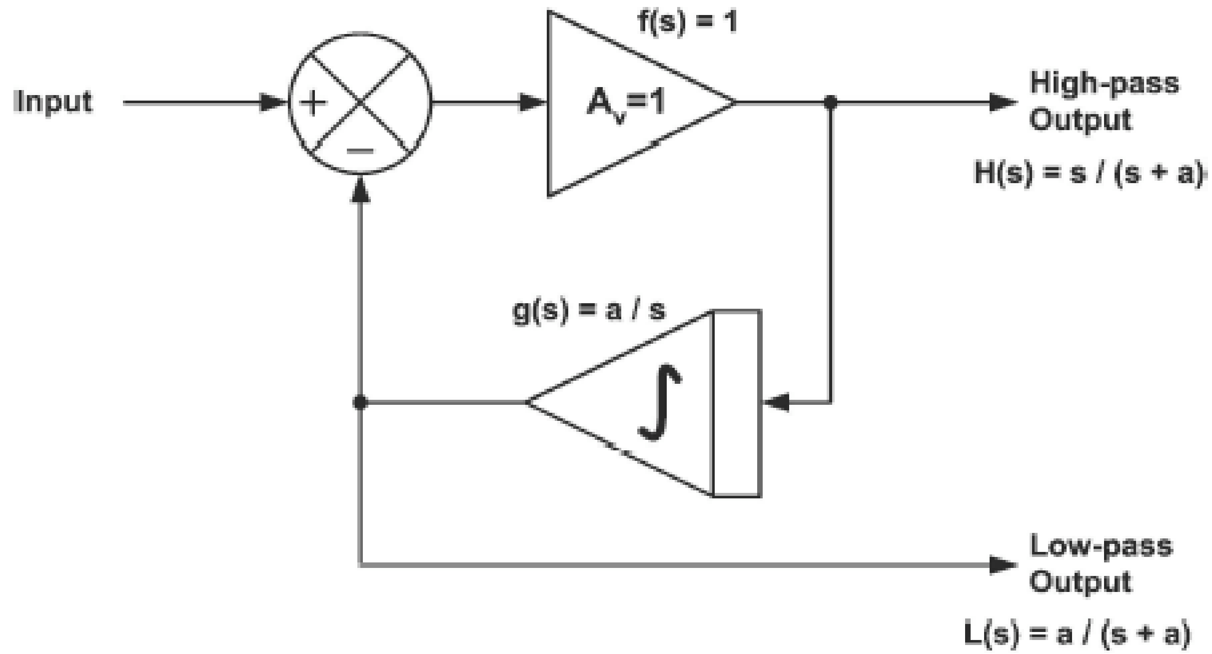
$$G_c(s) = K_c \frac{(s+a)}{(s+b)}$$

where K_C is a positive gain, $a < b$ for a lead compensator and $a > b$ for a lag compensator.


R4
1k
C
4.5nF
C
4.5nF
Ry
1k
R3
1k
R1
R2
1k
Rx
1k
R5
1k
Vin
Vout
C
4.5nF

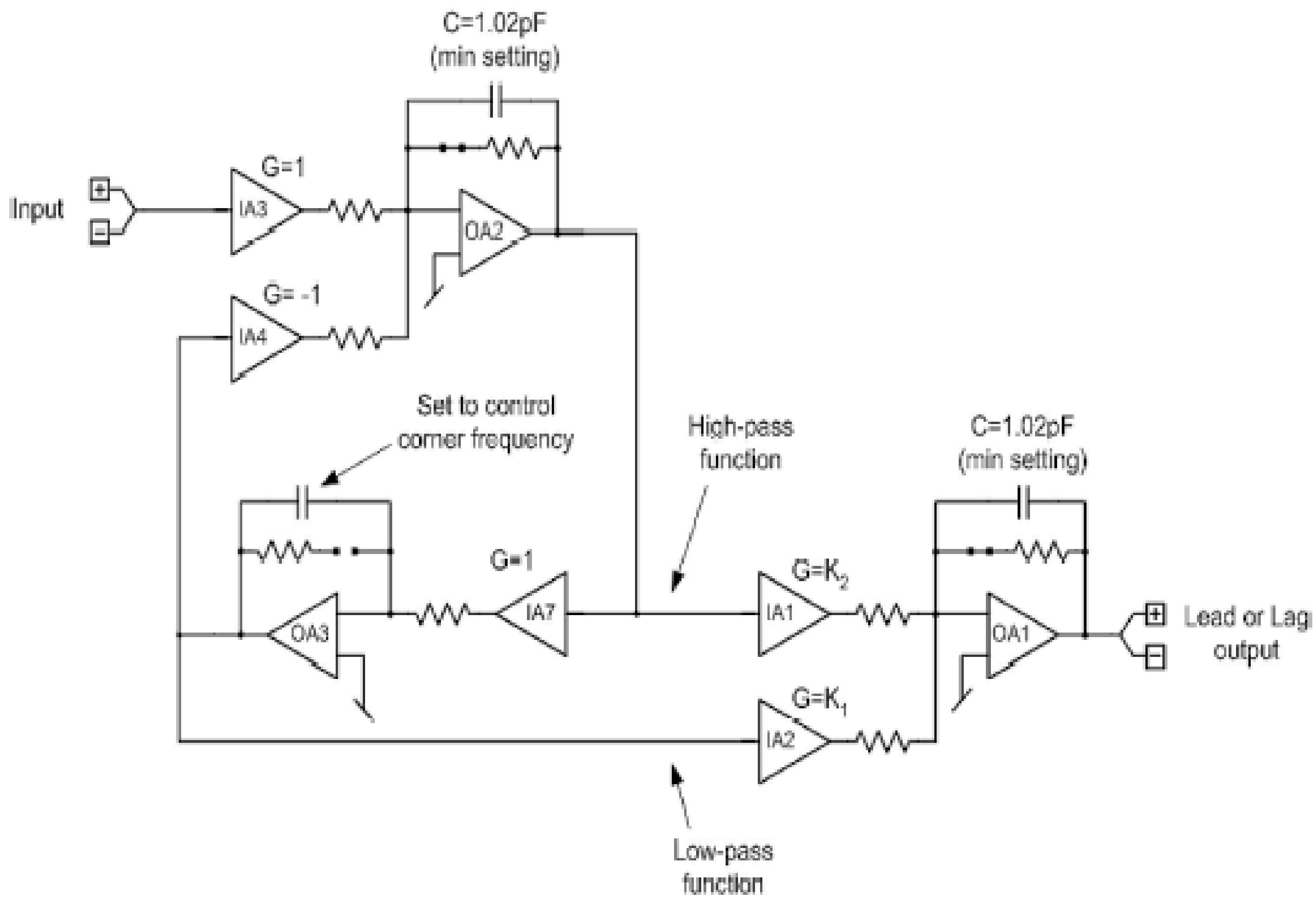


IA
IA
OA
IA
IA
OA
Analog Routing Pool
IA
IA
OA
IA
IA
OA
Reference
E2CMOS Memory
Auto-Cal
ISP Control
ispPAC10

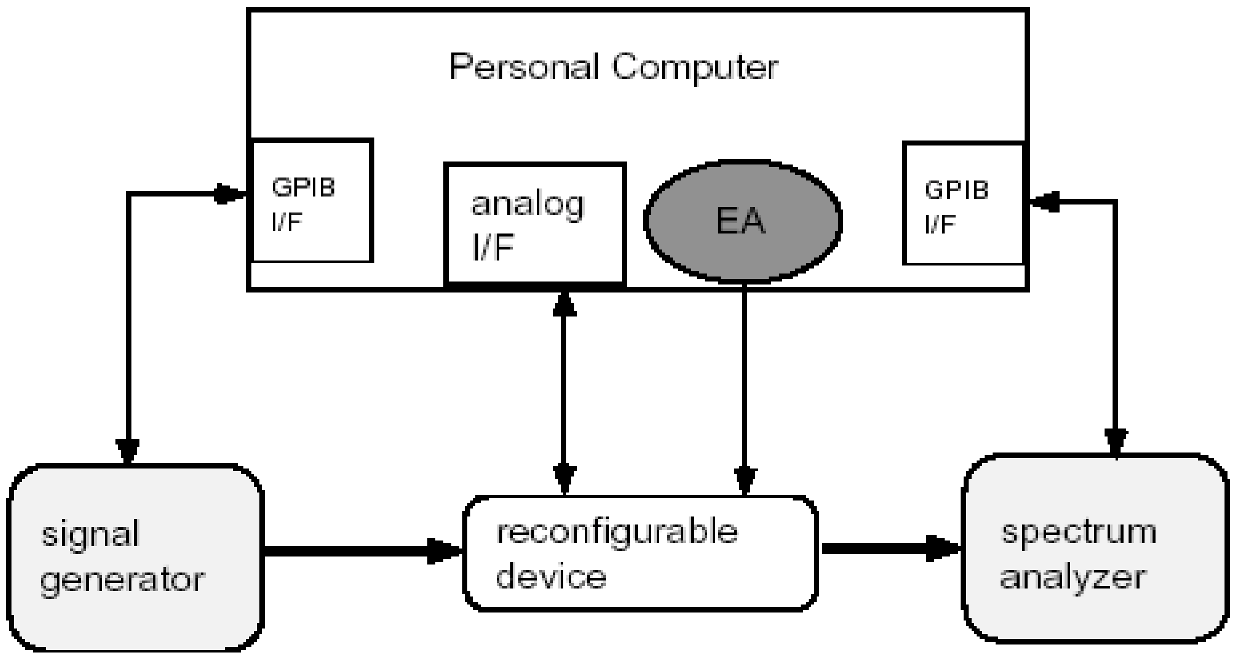


$$
\begin{aligned}
G(s) &= K_2 H(s) + K_1 L(s) \\
&= \frac{K_2 s}{(s+a)} + \frac{K_1 a}{(s+a)} \\
&= \frac{K_2 (s + \frac{K_1}{K_2} a)}{(s+a)}
\end{aligned}
$$

$K_1 < K_2$ lead compensator



C=1.02pF
(min setting)
Input
G=1
IA3
OA2
G= -1
IA4
Set to control
corner frequency
High-pass
function
C=1.02pF
(min setting)
G=1
IA7
OA3
G=K2
IA1
OA1
Lead or Lag
output
G=K1
IA2
Low-pass
function


Personal Computer
GPIB
I/F
analog
I/F
EA
GPIB
I/F
signal
generator
reconfigurable
device
spectrum
analyzer

Evolutionary Algorithm Details

population size:	20
offspring per parent:	1
selection method:	truncation
number of generations:	200
reproduction operators:	mutation (60%)
	recombination (40%)

NOTE: reproduction selected gain values and capacitor values

The fitness of configuration *C* is given by

$$fitness(C) = \sum_{i=1}^{5} \left[M(i) - \tilde{M}(i) \right]^2$$

where *M(i)* is the compensated magnitude response at the i-th frequency and $\tilde{M}(i)$ is the magnitude of the original (error-free) system.

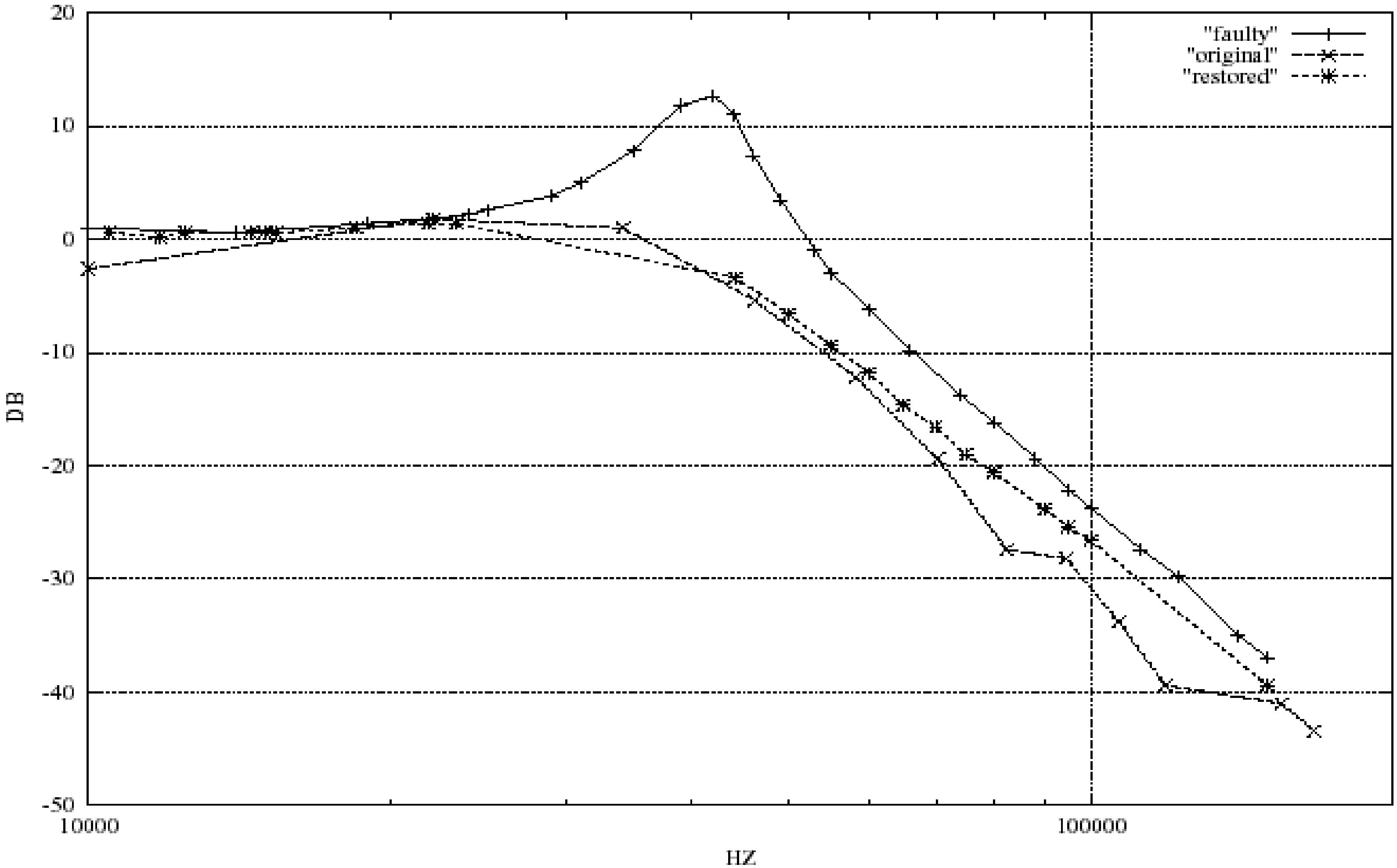
NOTE: just sampling the magnitude at the corner frequency results in the trivial solution (a simple gain change).

Changing Environment Experiments

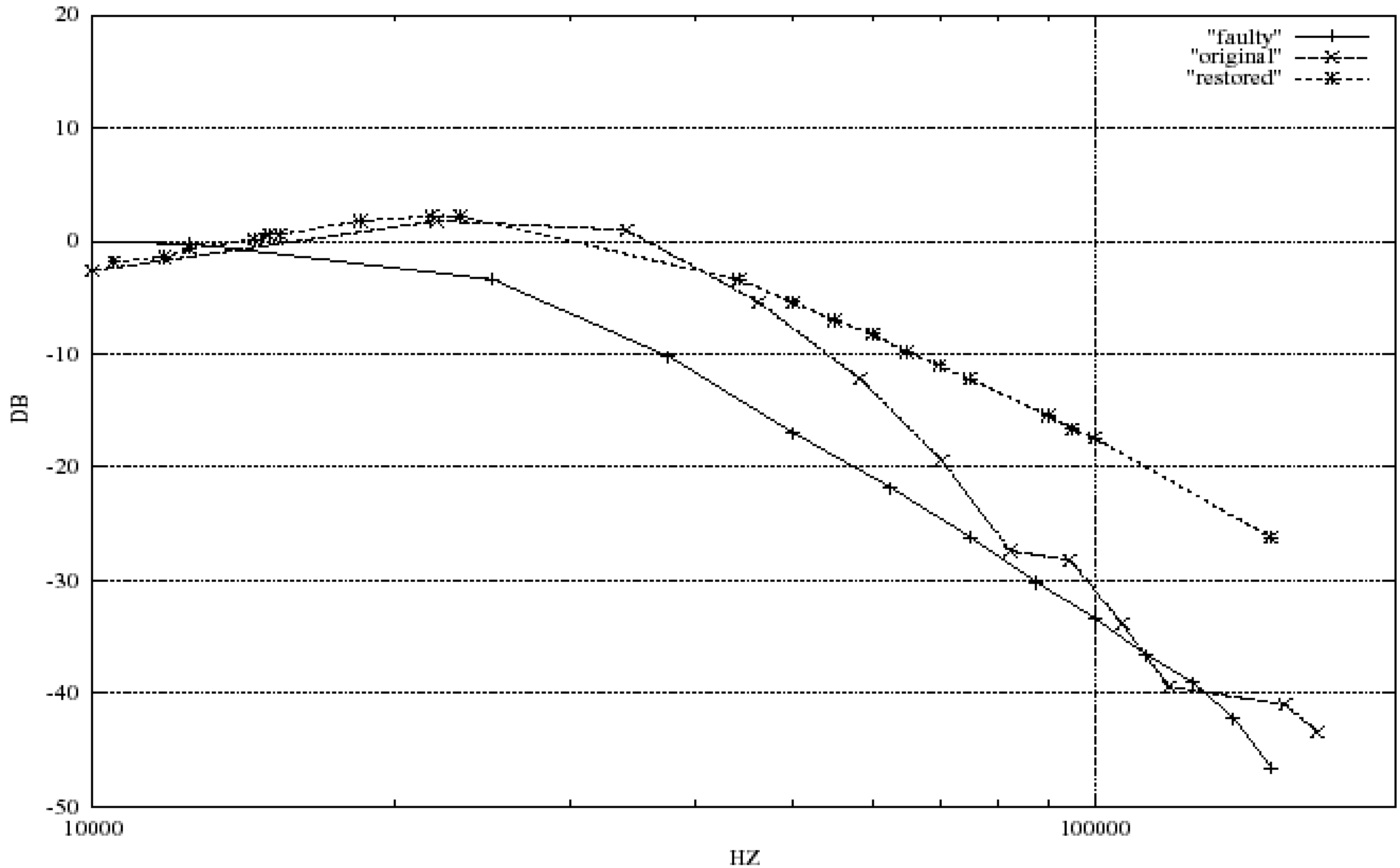
The plant transfer function is

$$G(s) \;=\; \frac{K}{s^3 + a_2 s^2 + a_1 s + K}$$

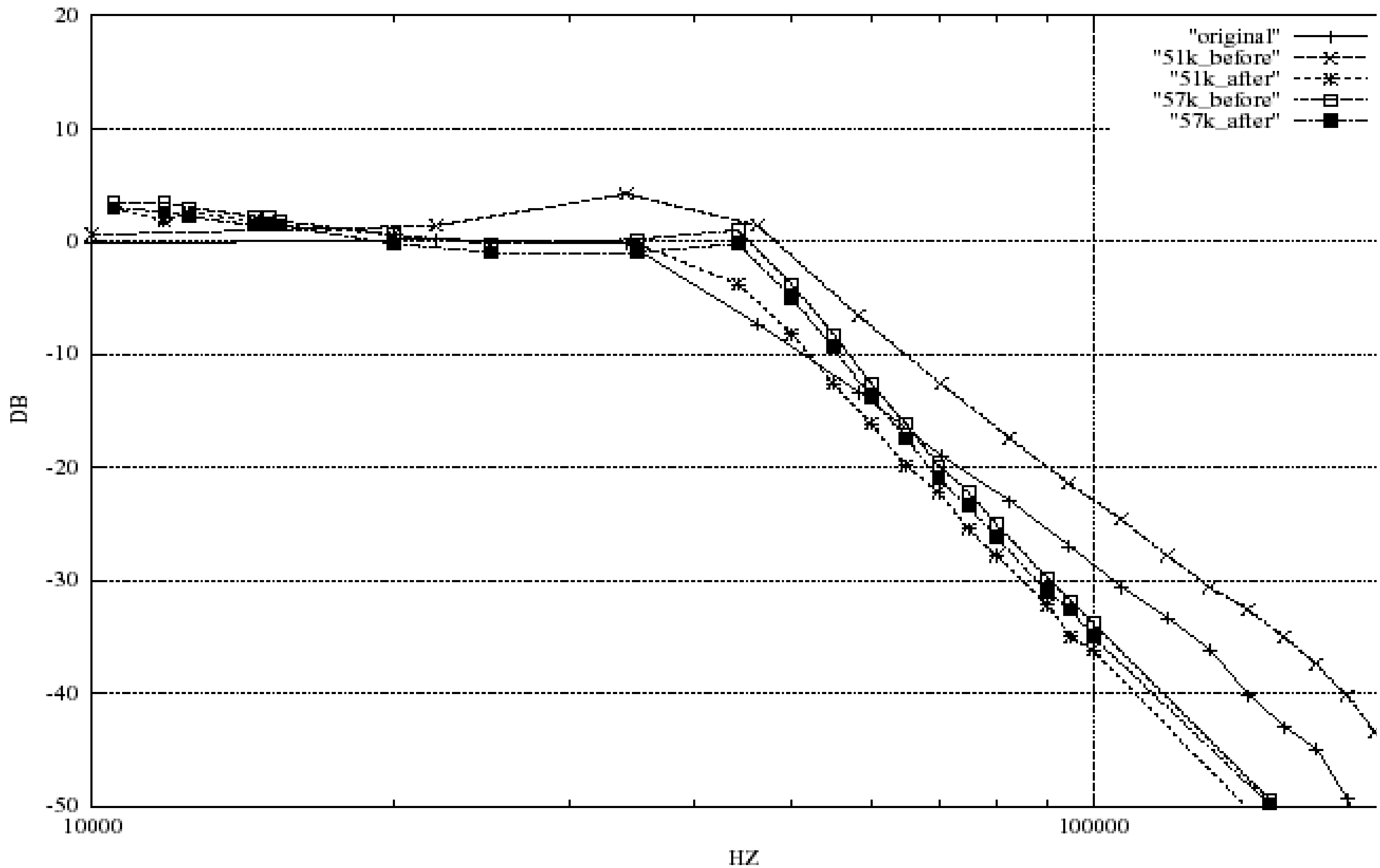
BW	notation	-3 dB point	compensation	K	a_2	a_1
original	S_O	44.25 kHz	none	1.097×10^{16}	3.422×10^5	7.605×10^{10}
reduced	S_R	31.07 kHz	lead	5.597×10^{15}	3.422×10^5	5.185×10^{10}
increased	S_I	53.0 KHz	lag	1.646×10^{16}	3.422×10^5	1.007×10^{11}



"faulty"
"original"
"restored"
20
10
0
-10
-20
-30
-40
-50
DB
10000
100000
HZ



"faulty"
"original"
"restored"
20
10
0
-10
-20
-30
-40
-50
DB
10000
100000
HZ



"original"
"51k_before"
"51k_after"
"57k_before"
"57k_after"
20
10
0
-10
-20
-30
-40
-50
DB
10000
100000
HZ

Some observations...

- *External compensation can be an effective fault recovery technique*

- *Many FPAAs have architectural limitations*

The ispPac10 can’t make an inverting amplifier, which only takes two resistors and an opamp.

- *Evolving structures at the circuit level is may be possible, but at the systems level it is not likely to be practical*

A resistor and opamp have 12 possible circuit configurations. □□w consider the circuit needed to create a compensator in the ispPAC10.

Future Work

Our work to this point has been restricted to <u>linear</u> plants. What about <u>non-linear</u> plants???? We intend to investigate

1. the type of non-linearities external compensation will work with

2. the type of compensator circuitry required

3. the real-time aspects of external compensation as a fault recovery method